CHAPTER VIII PHOSPHORUS BUDGET

A. DEVELOPMENT OF PHOSPHORUS BUDGETS

The calculation of a phosphorus budget is an essential step in the evaluation of a lake's trophic status. A phosphorus budget provides a means to evaluate and rank phosphorus sources that may contribute to algal problems. It is most important to determine the quantity of nutrients (especially phosphorus) entering the lake, as well as the ultimate fate of those nutrients. The phosphorus budget relies heavily upon the accuracy of the hydrologic budget for its input and output variables.

Many extensive nutrient budgets have been reported in the literature. Lake Washington in Seattle, Washington (Edmondson, 1972), Lake Erie (Burns, 1970), and Kezar Lake, North Sutton, New Hampshire (Connor and Smith, 1983) have been studied in great detail. Nutrient loading rates have been reported as either "surface loading rates" or "volumetric loading rates" and are usually expressed in terms of mass per unit area-time, or mass per unit volume-time.

This chapter will quantify the various avenues of phosphorus inputs into Great Pond and explore the various phosphorus sinks and exports from the watershed. Phosphorus loadings (flux) were calculated for each tributary inflow, outflow, direct runoff, atmospheric, groundwater, and septic leachate to Great Pond. A phosphorus budget was then prepared for the 1994-95 study year.

B. PHOSPHORUS BUDGET COMPONENTS

1. Tributary loading and discharge

Tributary phosphorus concentrations were analyzed and monthly loadings were calculated for each of the Great Pond tributaries. Tributary phosphorus loadings to Great Pond were tabulated during the twelve month study period. Phosphorus loadings were determined by calculating mean monthly tributary flows (10^3m^3) and multiplying these values by mean monthly phosphorus concentrations (mg/L). The resultant values represent mean monthly phosphorus loading or flux (kg P). The summation of the calculated monthly values equals the total tributary annual phosphorus loading.

Table VIII-1
Tributary Phosphorus Loading to Great Pond
(Study Year 1994-95)

Tributary	Flow Volume ($10^3 m^3$)	Mean Phosphorus Concentration (µg/L)	Phosphorus Loading (kg)	Phosphorus Loading (%)
Kelley	8970	18.2	124.9	67.8
Halfmoon	980	9.8	11.8	6.3
Thayer	855	30.1	26.6	14.5
Ball	811	28.1	20.5	11.1
Lincoln	22	5.9	0.5	0.3

Table VIII-1 shows the monthly tributary phosphorus load to Great Pond. Kelley Brook was the greatest tributary contributor of phosphorus to Great Pond providing 125 kg of phosphorus during the 1994-95 study year, or 68 percent of the tributary phosphorus load. Kelly Brook also contributed the greatest tributary supply of water to the lake (77 percent). Thayer Brook provided 14.5 percent (26.7 kg) of the tributary phosphorus loading to Great Pond but was the third largest source of water (7.3 percent) to the lake. The third greatest phosphorus producer to Great Pond was Ball Brook which donated 20.5 kg or 11.1 percent of the phosphorus load. The tributary that produced the second greatest amount of water to the pond (8.4 percent) contributed the least amount of phosphorus to the pond of the top four water contributors. The reason for this is that Halfmoon tributary had significantly lower phosphorus concentrations than these higher flowing tributaries.

The Lincoln tributary only provided 0.3 percent of the phosphorus to the lake and contributed less than 1 percent of the tributary inflow. Thayer Brook had the greatest phosphorus concentration when compared to other lake tributaries. Tributaries like Thayer Brook that consistently have high phosphorus concentrations are important as generally good candidates for sub-watershed management.

2. Atmospheric

Atmospheric inputs consist of two major components: (1) wind transported material, commonly referred to as dryfall, removed from the air by sedimentation or impaction; and (2) soluble gases or salts that are scavenged by rainfall. Estimates for the dryfall portion alone may be as high as 70-90 percent of the total atmospheric load (Likens and Loucks, 1978).

Increases in nutrient loads transported via the atmosphere can be attributed to agricultural activities and associated soil disturbances in agrarian areas. Urban atmospheric nutrient inputs may, in general, be attributed to combustion emissions.

Atmospheric phosphorus loading (wetfall and dryfall) for Great Pond was determined by the direct measurement of phosphorus in rain samples collected in Concord, New Hampshire (Table VIII-2); dryfall was calculated utilizing dryfall export coefficients (Reckhow, et al, 1980). By multiplying the mean phosphorus concentration calculated for the sample season, by the monthly rainfall and the lakes surface area, the atmospheric phosphorus loading was determined. This contributed 22.3 kg of phosphorus, with a mean monthly load of 1.9 kg, to Great Pond during the study period. Since the phosphorus load from atmospheric deposition is dependent on annual weather patterns, the greatest phosphorus contributions occur during the wettest seasons. The months of September and December contributed 31 percent of the total annual atmospheric phosphorus loading to Great Pond. Table VIII-2 predsents the monthly wetfall phosphorus conturbution to Great Pond during the study period.

Table VIII-2

Great Pond Wetfall Phosphorus Contributed

Month	Monthly Rainfall ($10^3 m^3$)	Mean Monthly Phos. Conc. (mg/L)	Kg. Phosphorus
Nov. '94	54.5	0.008	0.650
Dec. '94	108.1	0.020	3.240
Jan. '95	52.1	0.019	1.490
Feb. '95	53.6	0.023	1.850
Mar. '95	52.4	0.018	1.410
Apr. '95	37.1	0.049	2.730
May '95	56.1	0.034	2.860
Jun. '95	21.5	0.020	0.650
Jul. '95	53.6	0.029	2.330
Aug. '95	34.7	0.011	0.570
Sep. '95	56.9	0.042	3.590
Oct. '95	149.4	0.004	0.900
Total:	730.0	0.277	22.300

3. Direct Surface Runoff

Direct surface runoff includes the water and transported phosphorus not entering a lake via tributary or groundwater. Direct surface runoff is the result of near shore snowmelt and rainfall, especially during high intensity storms.

Loadings in runoff from shoreline areas can be estimated indirectly. In many cases, indirect estimates of loading from an area can be derived from information on watershed characteristics. This method is based on the concept that two watersheds in the same region and with similar land use patterns and geology will tend to contribute the same loading of phosphorus per unit area. This permits extrapolation of data from one or more monitored watersheds to others.

Shoreline runoff areas at Great Pond were designated as mixed forest, urban low density residential, and recreational. Table VIII-3 displays the selected export coefficient and total phosphorus export for each watershed designation. To evaluate the direct phosphorus runoff

Table VIII-3
Great Pond Watershed Phosphorus Export

Watershed Designation	Percent	Area (ha)	Export Coefficient (kg/ha/yr)	Phosphorus Export (kg)
Forested/Mixed	40.5	35.6	0.20	7.1
Urban/Low Density Residential	26.9	23.6	0.50	11.8
Wetland	32.6	28.7	0.25	7.2
Total	100.0	87.9	-	26.1

contribution to Great Pond, the designated land use areas that did not drain into a monitored tributary were determined. A phosphorus coefficient for each land use was selected by matching similar land uses at Great Pond to those with a known phosphorus export. The direct phosphorus runoff was calculated by multiplying the land use area by the phosphorus coefficient.

Increased phosphorus load to a lake from direct runoff corresponds to the area's weather patterns. Periods of frozen ground, snowmelt, and high intensity rainstorms usually contribute an increased phosphorus load via runoff.

Direct runoff contributed 26.1 kg of phosphorus to Great Pond during the study period. The mean monthly phosphorus contribution to Great Pond was 2.2 kg during the study year.

4. Septic Leachate and Groundwater Loading

Septic tanks and leach fields are additional non-point sources that must be considered nutrient sources due to their potential for nutrient enrichment of the groundwater flowing into a lake.

Several studies (Jones and Lee, 1977; NHWS&PCC, 1975) indicate that a properly designed, constructed, and maintained system will not generally contribute significant amounts of phosphorus to surface waters. However, because of their use in unsuitable areas or because of improper design, construction, or maintenance, it is estimated that over one-half of the systems in use today fail before their designed life of fifteen to twenty years is completed (Scalf et al., 1977).

The most common type of individual disposal system is the septic tank-leach field system. The tank functions to separate the solids, both floating and settleable, from the liquid material. The accumulated sludge should be pumped out every three to five years. The liquid is discharged from the tank through piping material and distributed over the leaching area, which is designed to absorb the effluent and to remove the impurities before it percolates to the groundwater.

In 1967, the New Hampshire legislature enacted a law to protect water supplies from pollution by subsurface disposal systems, and directed the Water Supply and Pollution Control Division to establish minimum, state-wide requirements for properly designed systems. The information required to estimate the phosphorus loading from septic systems is:

1. Location of the system with respect to the surface water body,
2. Soil permeability: the rate of water transmission through saturated soil, of which estimated soil retention coefficients varied with different lake sections,
3. Land slope: steep slopes may cause erosion problems when associated with soils of low permeability,
4. System age: soils have only a finite capacity for phosphorus absorption,
5. Per capita occupancy: (household population based on sanitary survey),
6. Fraction of year system is in use: (i.e., summer cottages or year-round dwellings), and
7. Additional water utilizing machinery: (e.g., washing machines, dish washers, or

garbage disposals).

For this study, a survey of individual sanitary waste-disposal systems around the lake was conducted. The survey consisted of a visual inspection of the property, interviews with residents to discuss various problems, and the compilation of certain statistical information regarding the system, such as type of system, age, maintenance schedule, depth to groundwater etc.

This data was used to calculate the septic leachate contribution to the phosphorus budget. Permanent and seasonal home phosphorus loading was calculated using the following equation:

kg P year^{-1} = (kg P Capita^{-1} year^{-1}) (# homes)(# Capita house^{-1}) (#years) (1-soil retention coefficient)

Where:

kg P Capita^{-1} year^{-1} = 0.48

Capita house^{-1} = 3.7

Soil retention coefficient = 0.8

#capitayears = 1 for year round and 0.3 for seasonal

The invention of new monitoring tools like the seepage meter and the Interstitial Pore Water Sampler (IPWS) have made groundwater sampling and analyses a more precise methodology. Whereas groundwater seepage and septic leachate had been treated as separate components of the phosphorus budget, they are now combined as one unit of the budget. Septic leachate phosphorus contributors were derived from the model equation and from actual interstitial water analyses combined with seepage rates. A comparison of phosphorus loading results from each method showed only a 24 percent (24 kg) difference in septic/groundwater phosphorus loading to Great Pond.

a. Sanitary Survey Summary. A sanitary survey was conducted at 44 of the estimated 115 shoreland septic systems (38 percent). The survey form (Appendix VIII-I) included questions on the type of system, system age, number of occupants, months of occupancy, distance of system from lake and slope of land to the lake. Table VIII-4 summarizes the results of the sanitary survey. Septic tanks and leach fields were the most common type of wastewater disposal representing 76 percent of the surveyed systems. A septic tank with chambers was the second most widely used wastewater system representing 12 percent of the systems. Chambered systems are relatively new and the number of these systems will increase with future development. Other systems used around the lake include cesspools, holding tanks and, chemical toilets.

Table VIII-4
Sanitary Survey Data Summary

System Type	Number of Surveyed Systems	Functioning Systems	Suspected Failures	Failed Systems
Septic Tank & Leach Field	92	77	5	10
Cesspool	3	2	0	1
Holding Tank	7	5	0	2
No Available Data	13	0	0	0
Survey Statistics				
Estimated Number of Systems Around Lake				115.0
Number of Survey Responses				44.0
Mean System Age (yr)				15.8
Per capita Mean Occupancy*				3.7
Mean Monthly Occupancy*				8.6

* Data derived from survey responses

The survey documented the average age of shoreline systems to be 15.8 years. Remember that the life expectancy of septic systems with leach fields is 15 to 20 years. The average occupancy of each shoreline dwelling was 3.7 people staying at the cottage for an average of 8.6 months. Many of the people living around the lake live there year-round rather than being transient home dwellers. Recent trends show that more people are making their lakeside dwellings year-round homes rather than just summer camps.

Although not included in the survey, we expect that septic system distances from the reference line reflected a variable range from less than 50 feet to greater than 250 feet. The most recent setback rules for septic system range from 75 feet to 125 feet depending on the soil characteristics.

The survey recorded 84 functioning systems with no problems, 5 systems that have potential problems and are suspected to be failing and 13 systems that are now in failure. The Great Pond Sanitary Survey Raw Data is presented in Appendix VIII-2.

b. Groundwater Phosphorus Monitoring. Relatively little is known of groundwater seepage nutrient concentrations and their importance to nutrient budgets. Lee (1977) first applied the direct seepage meter technique in Lake Sallie, Minnesota, in an attempt to monitor the contribution of nutrients from septic tanks located around the lake. Since anoxic conditions occur within the seepage meters after a period of time, direct measurement of phosphorus using this method may overestimate the groundwater contribution to the surface water. More recently, well water along the lake's boundary was analyzed to estimate nutrient input via seepage. The utilization of this type of methodology, however, does not account for nutrient concentration differences within the water table profile and does not include sediment interactions with seepage water (Connor, 1979). Biologists now derive groundwater phosphorus contribution to the lake by measuring the interstitial water concentration.

Groundwater monitoring was conducted throughout the shoreland area of Great Pond. A series of 11 seepage meters were placed along the shoreline area of Great Pond. Two sites had duplicate meters set up for quality control. A discussion of seepage meters and groundwater seepage rates can be found in Chapter VII.

Groundwater analyses for phosphorus concentration were conducted by monitoring 6 shallow dug wells along the shoreline and using a special sampling device to monitor the interstitial water at each seepage meter site.

Table VIII-5 presents the shallow well phosphorus data analyzed over the study year. The study year mean ranged from 3.7 μg/L, at the Ingalls well to 18.8 μg/L, at the Hicks well. All shallow wells were located from the mid section to the southern section of the lake. Sample analyses at shallow wells along the Great Pond shoreland revealed low to moderate phosphorus concentrations, similar to groundwater phosphorus concentrations measured in other groundwater studies (Beaver Lake, Derry: TP range = 1-30 μg/L and Robinson Pond, Hudson: TP range = 1-13 μg/L). The shallow well groundwater phosphorus were measured at the Hicks well, (14-25 μg/L P range) located in a developed section of the watershed to the southwest of

Great Pond and at the island (6-33 μg/L P range). The lowest concentrations were measured at the Ingall's well along the southwest shoreline (1-7 μg/L P range, mean = 3.7 μg/L P) and at the Hanson's well (1-9 μg/L P, 4.8 g/L P mean) located at the southern outlet port of the lake. Much of the western lake shoreline reflected moderate groundwater phosphorus concentrations.

Table VIII-5
Great Pond Shallow Dug Wells
Total Phosphorus Concentrations (μg/L)
November 1994-November 1995

Station Number	Range		Study Year Mean
	Minimum	Maximum	
Ingalls Well	1	7	3.7
Gallant Well	4	13	8.7
Hanson Well	1	9	4.8
Hicks Well	14	25	18.8
Island Well	6	33	14.5
Lincoln Well	2	7	5.3

A specially designed Interstitial Pore Water Sampler (IPWS), (Figure IV-3) was used to collect interstitial water at each of the seepage meter locations (Figure IV-4). The IPWS was placed in the sediment while interstitial water was pumped through a fine screen and into a sample bottle.

Table VIII-6 is a summary of the phosphorus analyses performed on interstitial water, while Figure VIII-1 illustrates the sample stations.

IPWS total phosphorus concentrations were significantly higher than the tributary and lake water samples, and significantly higher than groundwater measured from the area's shallow wells. The mean interstitial groundwater seepage phosphorus concentrations ranged from 82.7 μg/L to 456.0 μg/L. Although no quantitative analyses were performed at each IPWS Station, past studies have shown that there is a relationship between percent organic matter in the sediment and the amount of measured phosphorus in the interstitial water. As the percent organic matter increase, the phosphorus concentration at these sites increase.

Table VIII-6
Great Pond Interstitial Pore Water
Total Phosphorus Concentrations (µg/L)
November 1994-October 1995

Station Number	Range		Mean	Sediment Type
	Minimum	Maximum		
1	65	380	136.6	sand
2	40	231	110.6	sand
3	12	340	85.0	sand/gravel mix
4	43	288	164.7	sand/muck mix
5	199	942	406.0	sand/muck mix
6	63	502	226.9	sand/muck mix
7	23	226	82.7	fine grained sand
8	241	922	410.0	sand/gravel mix
9	129	1,574	456.0	sand/gravel mix
10	20	266	119.3	muck/sand mix
11	121	684	253.1	sand

The highest phosphorus concentration measured in the interstitial water of Great Pond was at Station 9 (Range=129-1,574, mean = 456.0). Four of the five highest mean phosphorus concentrations, were measured in interstitial water located on the western shore. The lowest amounts of interstitial water phosphorus was measured at Station 7 (Range=23-226, mean=82.7) and Station 3 (Range=12-340, mean=85.0). The lowest mean interstitial phosphorus concentrations were measured in the north stations nad the west lake station.

Groundwater seepage and septic leachate phosphorus contributors were derived from the direct measurement of groundwater seepage and phosphorus analyses of interstitial water. Actual loading (kg P) was calculated using groundwater seepage rates ($10^3 m^3$) and interstitial phosphorus concentration (μg/L-P). Groundwater seepage and leachate contributed 206 kg of phosphorus to Great Pond, representing 20 percent of the Great Pond phosphorus budget. Septic leachate and groundwater seepage loading to Great Pond was similar to the loading of four recently completed Diagnostic/Feasibility Studies: French Pond, Henniker (Connor and Martin 1988) and Mendums Pond, Barrington (Connor, McCarthy and O'Loan, 1992) at 24 percent, Beaver Lake, Derry (Connor and O'Loan, 1992) at 25 percent and Keyser Pond, Henniker (Connor and Martin, 1988) at 18 percent.

In summary, several groundwater sources were sampled throughout the Great Pond study. These groundwater sources included well water from drinking water sources around the lake, and interstitial water from the sediments of Great Pond. Although the results showed that the dug wells surrounding the pond had relatively low phosphorus concentrations, only the interstitial phosphorus analyses were utilized to calculate the phosphorus loading component to the budget. The groundwater interacts with the phosphorus rich sediments and with septic leachate water, contributing to higher amounts of phosphorus in the interstitial water. It is the interstitial water which more accurately reflects the phosphorus load to the lake via groundwater seepage.

5. Sediment Release and Uptake

a. Introduction. The fate of phosphorus in water is usually considered to consist of chemical, physical, or biological transformation of the ionic form into a particle, sedimentation of this particle to the bottom, particle breakdown in the sediment, and the release of some of the ionic phosphorus back into the lake water if conditions are favorable. Anoxic conditions favor a decrease of internal phosphorus loading because the phosphorus can sorb to oxidized iron complexes. There may be other sources of internal loading that could be more significant than the release from pelagic sediments into anoxic overlying water. These could include aerobic release from littoral sediment, plant decomposition, or littoral release from photosynthetically caused high pH.

The actual measurement of total phosphorus release or uptake from the sediment is an impractical task to attempt. Since sediment release and uptake are occurring simultaneously in different sections of a lake, and other chemical, physical and biological activities are also occurring, it is virtually impossible to establish a realistic total phosphorus release or uptake figure. However, an estimation of net differences between total uptake and total release can be derived by calculating an internal phosphorus loading model. A positive mass balance solution represents net phosphorus release (loading) and a negative solution represents net uptake.

b. Internal Phosphorus Cycling. An essential component of the nutrient budget is the monthly net release or uptake of phosphorus from or to the lake sediments. In order to quantify this component, a phosphorus mass-balance equation was solved for each month of the sample period. Thus, by knowing the masses of phosphorus entering the lake and flowing out of the lake and the change of mass in the lake, the equation can be solved for the mass released or adsorbed by the sediments.

Mass is calculated as the product of concentration and volume. Table VIII-7 shows how the phosphorus mass in Great Pond at the beginning of each month was calculated as the sum of masses in each stratum. The volume of each stratum was calculated from areal measurements of contours on the bathymetric map.

Table VIII-8 reflects monthly values of each variable of the mass-balance equation and the resulting net uptake or release from Great Pond sediment.

The mass-balance equation is:

$P_{int} = (P_2 - P_1) - (P_{in} - P_{out})$

where:

P_{int} = net phosphorus release (+) or uptake (-) by the sediments

P_1 = in-lake phosphorus mass, beginning of month

P_2 = in-lake phosphorus mass, end of month

P_{in} = phosphorus mass flowing in during the month

P_{out} = phosphorus mass flowing out during the month

Table VIII-7
In-Lake Phosphorus Mass for Great Pond

Month	Thermal Layer	P Conc. (µg/L)	P mass (kg P)	Total Monthly P (kg P)
November 1994	Upper	10.5	13.7	14.6
	Lower	11.0	0.9	
December 1994	Upper	13.0	16.2	17.3
	Lower	14.0	1.1	
January 1995	Upper	11.0	13.7	14.7
	Lower	11.5	1.0	
February 1995	Upper	10.0	12.5	13.4
	Lower	10.5	0.9	
March 1995	Upper	10.5	13.7	14.7
	Lower	11.5	1.0	
April 1995	Upper	11.5	15.0	15.9
	Lower	11.0	0.9	
May 1995	Upper	12.0	15.0	16.2
	Lower	15.0	1.2	
June 1995	Epilimnion	8.9	9.8	13.0
	Metalimnion	13.0	3.0	
	Hypolimnion	16.4	0.2	
July 1995	Epilimnion	9.1	9.8	13.0
	Metalimnion	13.0	3.0	
	Hypolimnion	23.2	0.2	
August 1995	Epilimnion	9.6	10.9	13.7
	Metalimnion	11.0	2.5	
	Hypolimnion	28.2	0.3	
September 1995	Epilimnion	10.3	10.9	13.9
	Metalimnion	12.0	2.7	
	Hypolimnion	32.1	0.3	
October 1995	Upper	15.0	18.7	22.5
	Lower	48.0	3.8	

Figure VIII-I demonstrates the capacity of Great Pond to assimilate phosphorus. Great Pond acts as a phosphorus sink, accumulating phosphorus from the watershed and lake in the sediments. Great Pond assimilated phosphorus for twelve months of the study year. The months of December, April, May and October were maximum uptake months, where sediment phosphorus uptake was greater than 26 kg P/month. Both December and October showed phosphorus uptake of 35 and 47, respectively. Two months (February and September) showed a near balance of phosphorus exchange between the lake at its sediments. The total net sediment uptake of phosphorus from the lake was 241.6 kgP.

Table VIII-8

Monthly Internal Phosphorus Cycling

Great Pond 1995 Gaging Year

Month	P_{in} Subtotal Inflow	P_{out} Total Outflow	P_{lake} 1 (kg)	P_{lake} 2 (kg)	P_{int} (kg)
Nov 94	23.0	6.1	14.6	17.3	-14.2
Dec 94	54.4	22.1	17.3	14.7	-34.9
Jan 95	48.8	34.4	14.7	13.4	-15.7
Feb 95	32.5	25.0	13.4	14.7	-6.2
Mar 95	49.0	32.0	14.7	15.9	-15.8
Apr 95	40.0	13.5	15.9	16.2	-26.2
May 95	33.7	10.1	16.2	13.0	-26.8
Jun 95	15.7	4.3	13.0	13.0	-11.4
Jul 95	24.1	1.2	13.0	13.7	-22.2
Aug 95	12.7	0.9	13.7	13.9	-11.6
Sept 95	19.7	1.2	13.9	22.5	-9.9

Oct 95	43.5	4.7	22.5	14.6	-46.7
				Total	241.6

P_{in} = monthly subtotal of all P inputs (from P budget)
P_{out} = monthly outflow from outlet (from P budget)
P_{lake} 1 = monthly P (kg)
P_{lake} 2 = subsequent monthly P (kg)

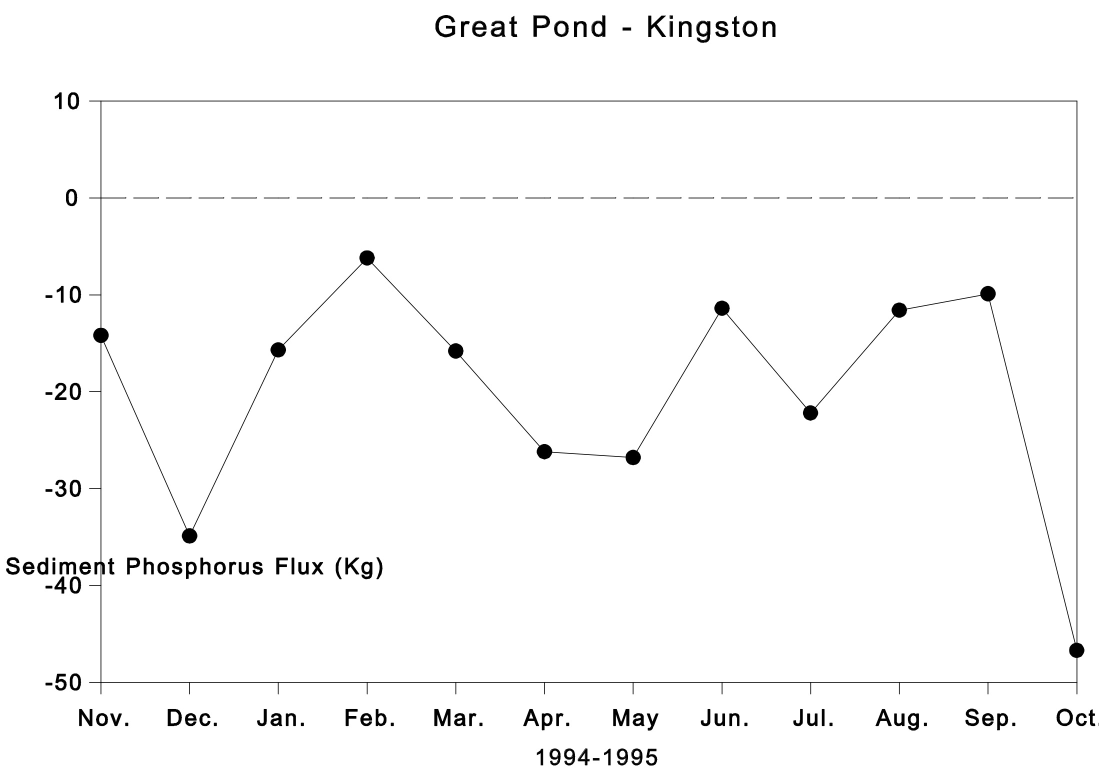


Figure VIII-1: Net Sediment Phosphorus Flux and Phosphorus Assimilation

C. SEASONAL PHOSPHORUS CONTRIBUTIONS TO GREAT POND (1994-1995)

The monthly and total phosphorus budgets were derived from the aforementioned components and measured phosphorus concentrations. The following discusses monthly or seasonal phosphorus loading by each of the components to Great Pond.

Budget components and phosphorus data were derived for the months of November, 1994 through October, 1995. Monthly phosphorus loading to Great Pond by the major in-flowing tributaries is presented in Figure VIII-2, while Figure VIII-3 shows the total phosphorus load from all the in flowing tributaries. Although the project's sample year was considered dry by comparison to the state's annual mean rainfall records, the seasonal phosphorus loading patterns for the major in flowing tributaries coincided with expected geographic and climatic trends. Phosphorus loading to the lake will fluctuate with the hydrologic year; a wet year will increase the phosphorus load to the lake while a dry year will decrease the phosphorus load to the lake. Total loading is directly related to the volume of water entering the lake and to the water velocity of runoff flowing from the watershed into the tributary. As the velocity of water runoff increases, the concentration of total and dissolved solids increase.

Typically, December, January and sometimes February show a decreasing trend in phosphorus loading to the lake because, much of the watershed runoff and phosphorus stripping is minimal as water is being stored as ice and snow. There is usually little winter snowmelt and therefore little phosphorus loading from the watershed. This was not the case at Great Pond during the 1995 winter season. The months of December, January and February ranked first in seasonal loading accounting for 43.3 percent of the annual phosphorus load to Great Pond. Over 60 percent of the phosphorus loading during the winter months was attributed to Kelley Brook. The high phosphorus load to the lake may be the result of high rainfall and warmer temperatures during the winter season, especially during the month of December. Almost 30 percent of the annual wetfall occurred during the winter season.

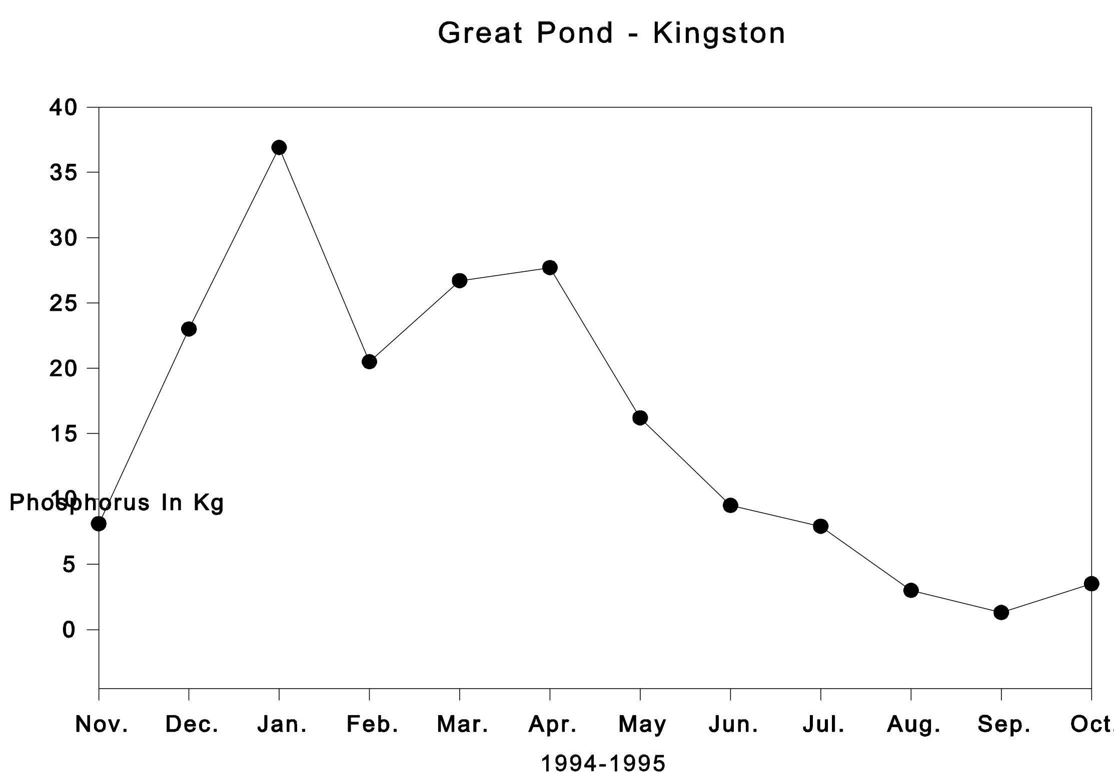


Figure VIII-3: Monthly Phosphorus Load by Inflowing Tributaries

Much of the monthly phosphorus loading usually occurs in late February, March and April when winter snowmelt erodes subwatershed particulate material and strips the phosphorus that accumulated since late fall. This high phosphorus load attributed to the snow pack is a result of an accumulation of atmospheric particulate fallout onto the snow as well as the phosphorus concentration in the snow itself. The spring season is also a time when the ground is still partially frozen and little infiltration into the ground occurs. However, the upper sediment layers are continually being thawed during the day and frozen during the night. This freeze/thaw process causes the destabilization of some vulnerable sediments. The result is an acceleration of the movement of these unstabilized sediments toward the lake.

During the study year spring season, 38 percent of the annual phosphorus load was delivered to Great Pond. Kelley Brook represented 79 percent of the phosphorus load to the pond during the spring season.

The number two ranking of phosphorus loading to the pond during the spring as compared to the winter can only be explained by the atypically warm and wet winter season, which resulted in increased watershed runoff and phosphorus stripping. By May, much of the phosphorus loading to the lake had subsided. During May, the subwatersheds are usually dry and the soils are stabilized with a healthy growth of vegetation.

The summer months of June and August were extremely dry, representing 2.9 and 4.7 percent, respectively, of the annual wetfall (see Table VII-1), while several short-term storms in July provided 7.3 percent of the annual wetfall. Kelley Brook provided 79 percent of the phosphorus load (7.5 kgP) during June, while Ball Brook contributed the bulk of the July phosphorus load (80 percent, 7.9 kgP) (Table VIII-9).

Although the apparent trend for July and August was a decreased phosphorus load, these months are usually underestimated. Typically, these months are the driest, and ground infiltration and evapotranspiration are at their maximum. Much of the water and nutrients are being taken up by the unsaturated soils and the lavish plant growth. However, these months also are characterized by short duration, high intensity storm events. These events are difficult to measure and, in fact, usually overload the hydrologic and phosphorus budget unless flows are being monitored by in-stream gaging devices.

Table VIII-9

Great Pond Phosphorus Budget for Gaging Period (Nov ‘94 - Oct ‘95) (Kg P)

Component	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total Annual	Mean Monthly
Qi_1 - Kelley	6.0	11.9	22.4	16.8	20.6	22.5	12.7	7.5	1.2	1.6	0.6	1.1	124.9	10.4
Qi_2 - Halfmn.	0.8	2.8	2.7	1.7	2.1	1.1	0.4	0.2	0.0	0.0	0.0	0.0	11.8	1.0
Qi_3 - Thayer	0.6	5.9	10.0	1.3	2.1	2.5	1.8	0.7	0.4	0.6	0.0	0.7	26.6	2.2
Qi_4 - Ball	0.7	2.3	1.8	0.7	1.7	1.4	1.3	1.1	6.3	0.8	0.7	1.7	20.5	1.7
Qi_5 - Lincoln	0.0	0.1	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Tot. Trib. Load	8.1	23.0	36.9	20.5	26.7	27.7	16.2	9.5	7.9	3.0	1.3	3.5	184.3	15.4
R	2.0	3.9	0.0	0.0	5.7	1.3	2.0	0.8	1.9	1.3	2.0	5.4	26.3	2.2
P_{lake}	0.7	3.2	0.0	0.0	4.7	2.7	2.9	0.6	2.3	0.6	3.6	0.9	22.2	1.9
GW_i	12.2	24.3	11.9	12.0	11.9	8.3	12.6	4.8	12.0	7.8	12.8	33.7	164.3	13.7
Total P Load	23.0	54.4	48.8	32.5	49.0	40.0	33.7	15.7	24.1	12.7	19.7	43.5	397.1	33.1
Uptake (-)	-14.2	-34.9	-15.7	-6.2	-15.8	-26.2	-26.8	-11.4	-22.2	-11.6	-9.9	-46.7	-241.6	-20.1

Total Influx	8.8	19.5	33.1	26.3	33.2	13.8	6.9	4.3	1.9	1.1	9.8	-3.2	155.5	13.0
Outflow Load	6.1	22.1	34.4	25.0	32.0	13.5	10.1	4.3	1.2	0.9	1.2	4.7	155.5	13.0

Tributary phosphorus loading to Great Pond reached a study year minimum in September. Much of the September rainfall was probably absorbed by the dry watershed and the watershed vegetation. It is also likely that the storms were of larger duration and lower intensity, favoring more ground penetration, rather than direct overland runoff. October represented the highest percent of wetfall during the study year, contributing to 20.5 percent of the annual wetfall budget (Table VII-1). As the late fall wetfall increased and the growing season ended, phosphorus loading to the pond increased, during both October and November to 3.5 kgP and 8.1 kgP, respectively (Table VIII-4).

Monthly external phosphorus loading trends, exclusive of tributary loading, are presented in Figure VIII-4.

Atmospheric contributions depend upon the amount of precipitation that occurs over a given period of time. Atmospheric contributions and runoff loading during the winter months are often low, since precipitation is usually in the form of snow, and runoff is slight. As the phosphorus budget reveals (Table VIII-9), the greatest single monthly atmospheric contribution occurred in March when 21 percent (4.7 kgP) of the atmospheric phosphorus load entered the lake. September was the second highest contributor of atmospheric phosphorus with 16 percent or 3.6 kgP, while December contributed 14.4 percent and may contributed 13 percent. The mean monthly contribution was 1.9 kgP from wetfall sources.

Direct runoff of water to the lake is dependent on precipitation, soil conditions and the season. Generally, the spring melting of the winter snowpack, in combination with semi-impermeable frozen soils, lead to high direct phosphorus runoff. During warmer months, high intensity rain events also increase direct runoff of phosphorus, as little of the fallen precipitation has the opportunity to percolate through the soils. Low intensity storm events normally produce little direct phosphorus runoff from non-urbanized watersheds, since much of the water is absorbed into the usually dry summer soils.

Seasonally, little direct runoff was calculated for the winter months for Great Pond. Direct phosphorus runoff increased during March when the snowpack melted, and significantly decreased during April, May, and June, when wetfall was low and the growing season was underway. The direct phosphorus runoff is related to the seasonal weather patterns of the area: phosphorus loading from runoff increases as rainfall increases. Only the months of December, March and October produced phosphorus loading to Great Pond greater than the study year monthly mean of 2.2 kgP. The combined summer season produced only 4.0 kgP for Great Pond.

Groundwater seepage loading of phosphorus to the lake also followed seasonal patterns. As more water is delivered to the aquifer, increased pressure forces more water and phosphorus into the lake. In the same manner, an increase in septic system usage will increase both the quantity of water in the saturated lake shoreland water table, and the nutrient loading to the groundwater. Usually winter months are lower because less surface water can penetrate the frozen ground. Lake seepage rates increase in the spring when the ground is well thawed and becomes more saturated with water. Seepage phosphorus loading varies throughout the summer months depending on the hydraulic gradient and the use of septic systems. High groundwater

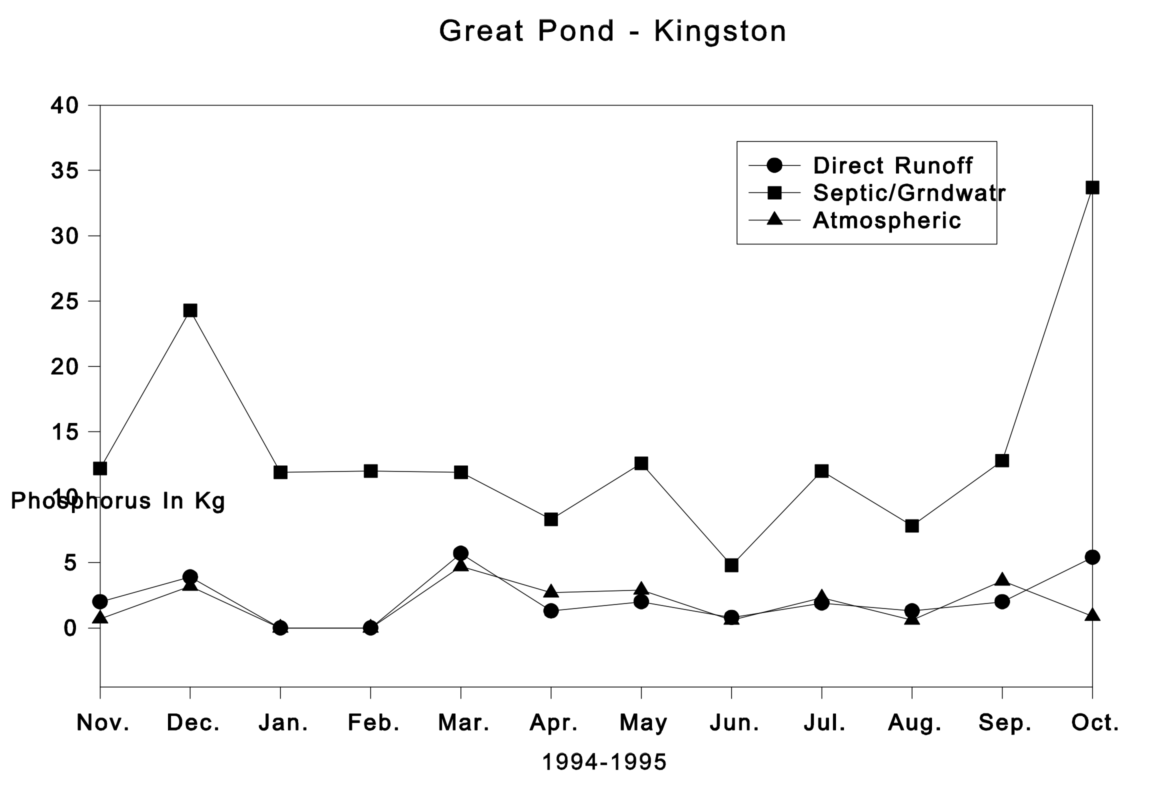


Figure VIII-4: Monthly External Phosphorus Load to Great Pond (Exclusive of Tributaries) phosphorus loading continues to occur through most of the fall, with septic systems still functioning and an increase in October precipitation.

Figure VIII-5 presents total monthly external loading over the 1994-1995 study period Maximum phosphorus loading was achieved during December, January, and March. These three months yielded 38 percent of the annual phosphorus load to Great Pond. However it is important to note again that phosphorus loading during July and August are probably underestimated because of the high intensity, short duration storms that are difficult to monitor.

Three months, June, August and September, were well below the annual mean phosphorus contribution of 33.1 kgP. These were months of low wetfall. October was above the mean monthly phosphorus contribution, February and May proved to be periods where average amounts of external phosphorus was entering Great Pond.

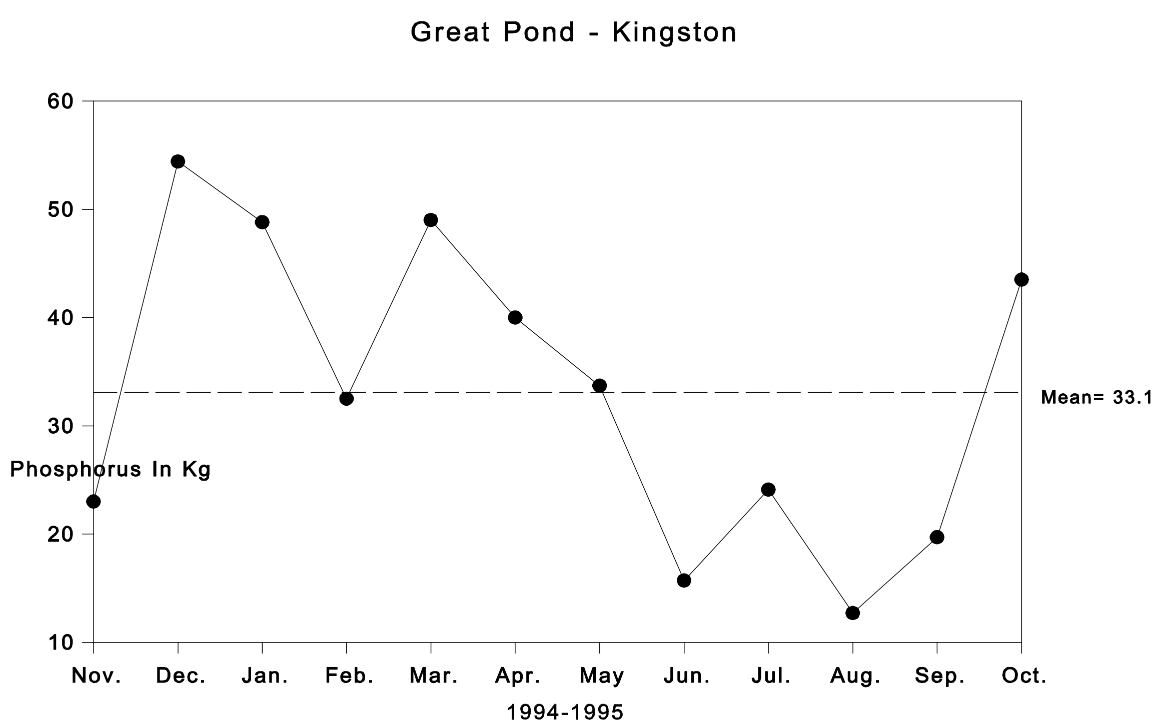


Figure VIII-5: Total Monthly External Loading

D. ANNUAL PHOSPHORUS BUDGET FOR GREAT POND (1994-1995)

The total phosphorus budget as a whole and the percent contribution of each component to Great Pond is one of the most important products of this study.

A pie diagram (Figure VIII-6) shows the external phosphorus contribution to Great Pond as percent of the total budget, while Table VIII-9 presents the 1994-1995 gaging year phosphorus budget for Great Pond. The combination of all five in flowing tributaries to Great Pond accounted for 46.4 percent of the phosphorus budget. When compared to other Diagnostic/Feasibility Studies throughout New Hampshire, the tributary loading portion of the Great Pond budget was similar to that of Pawtuckaway Lake, Nottingham, (Connor and Landry, 1995), which contributed tributary phosphorus load of 45 percent, and was greater than Robinson Pond, Hudson (Connor et.al., 1994), which contributed over 34 percent of the phosphorus flux. Tributary phosphorus loading to Great Pond was less than Beaver Lake at 65 percent (Connor and O'Loan, 1992) and less than both French Pond (Connor and Martin, 1988) and Kezar Lake (Connor and Smith, 1983), both had a tributary contribution of 73 percent of the phosphorus budget.

Groundwater seepage was the second greatest contribution of phosphorus to Great Pond. Groundwater seepage contributed 41.4 percent of the phosphorus load to the pond. The large encompassing littoral area, the amount of older first and second tier septic systems and the sediment composition all were contributing factors in the high groundwater input. The combination of septic system contributors to the groundwater and chemical reactions in the sediment-water interface influence the phosphorus groundwater concentration.

The combination of high seepage rates, with relatively high interstitial phosphorus concentrations makes Great Pond the highest groundwater contributor when compared to other Diagnostic/Feasibility Study lakes. Seepage phosphorus contributors generally range from nine to ten percent of the phosphorus budget. However, Robinson Pond groundwater contributed 27 percent and Pawtuckaway Lake groundwater contributed 20 percent of the phosphorus load to the lake. The recent increase of groundwater phosphorus loading to lakes may also be attributed to new technology recently adopted by the Biology Bureau. The measurement of interstitial groundwater phosphorus concentration and actual flow determinations are being used over model equations to define the groundwater phosphorus contribution to the budget.

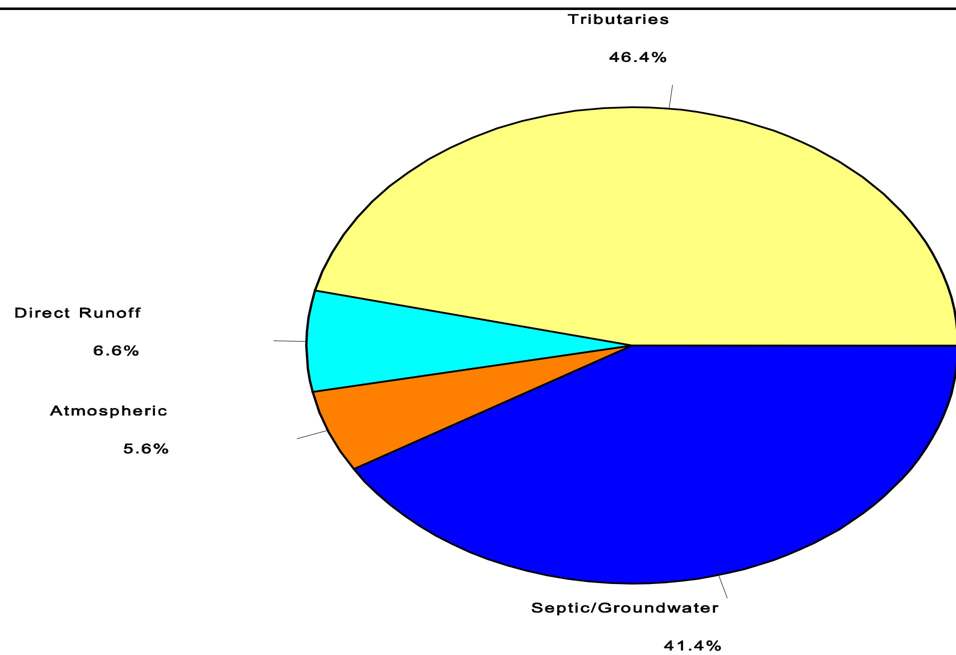


Figure VIII-6 External Phosphorus Contribution to Great Pond

Direct runoff was the third greatest contributor of phosphorus to Great Pond. The small amount of watershed surface area, that is not drained by tributaries surrounding the lake, accounts for the direct runoff portion of the phosphorus contribution to Great Pond. Since most of the direct drainage area is comprised of forest and low impact development, the phosphorus coefficients are low. The combination of small drainage basin and low phosphorus runoff coefficients translate into a low phosphorus runoff of 26.3 kgP, or 6.6 percent of the annual phosphorus budget.

Atmospheric deposition delivered 22 kg of wetfall and dryfall phosphorus to Great Pond during the 1994-1995 study year. This contribution represents 5.6 percent of the phosphorus budget and compares well to other studies completed.

Oxygen deficiencies were measured in the hypolimnion of Great Pond for approximately 30 percent of the study year. Hypolimnetic anoxia is highly conducive to the release of phosphorus from the sediment and interstitial water to the immediate water column. Increases in hypolimnetic phosphorus in Great Pond coincided with low hypolimnetic dissolved oxygen during July, August, and early September. Hypolimnetic phosphorus and dissolved oxygen data reveal that there is currently a problem with internal phosphorus loading. Since this hypolimnetic area reflects internal phosphorus loading to the lake, much of the other lake areas must be accumulating phosphorus.

Although the Great Pond phosphorus budget shows a net uptake of phosphorus, it must be emphasized that sediment release and uptake are simultaneously occurring functions in different sections of the lake, and that other chemical, physical and biological activities are also occurring. While one section of the lake may be releasing phosphorus for some of the year, other areas of the lake are taking up phosphorus. As discussed previously in the sediment release section, no one month showed a net release of phosphorus to the water column. Hypolimnetic phosphorus data collected during the 1995 summer study period confirmed that internal phosphorus loading is a problem in Great Pond. A comparison between epilimnetic phosphorus (mean = 10.6 µg/L) and hypolimnetic phosphorus (mean = 29.4 µg/L) shows that hypolimnetic phosphorus was almost 3 times greater than epilimnetic phosphorus over the same period of time.

E. STORM EVENT PHOSPHORUS LOADING TO GREAT POND

Storm events can be a significant factor in calculating a phosphorus budget. However, they are one of the most difficult parts of the budget to quantify. Accumulating storm event data can be costly; equipment to sample and record flows must be purchased and operated. Nonetheless, the expense is justified if an accurate phosphorus budget is to be developed. Dennis (1986) estimated that the four largest runoff events accounted for 65 percent of the total phosphorus export to a Maine Lake, and a single storm event contributed almost 50 percent of the phosphorus load to that same lake.

Many studies have shown that much of the phosphorus load can occur during the first centimeter of rainfall. A study conducted in a Maine watershed estimated that 69 percent of the phosphorus export occurred during the first centimeter of runoff, while 90 percent and 97 percent occurred during the first 2cm and 3cm, respectively.

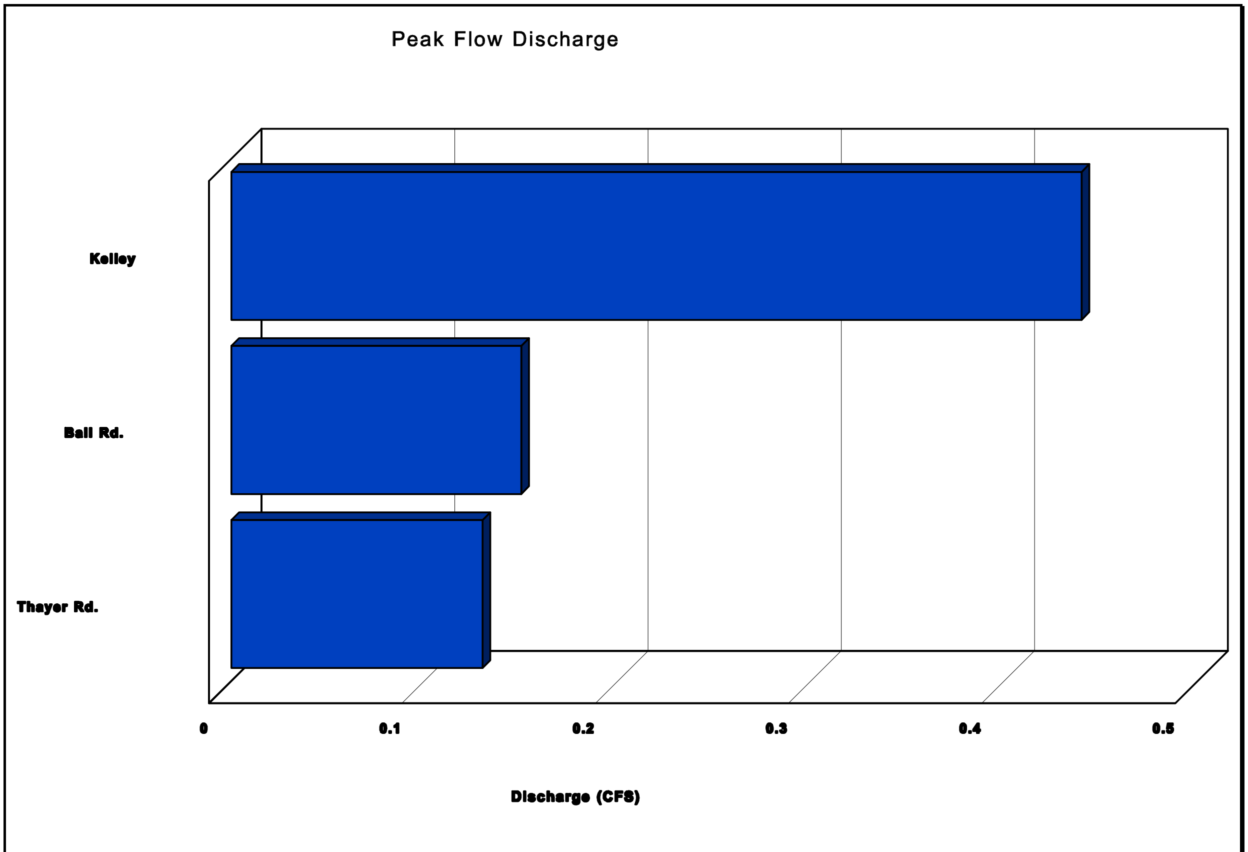


Figure VIII-7 Storm Event Peak Flow Discharge

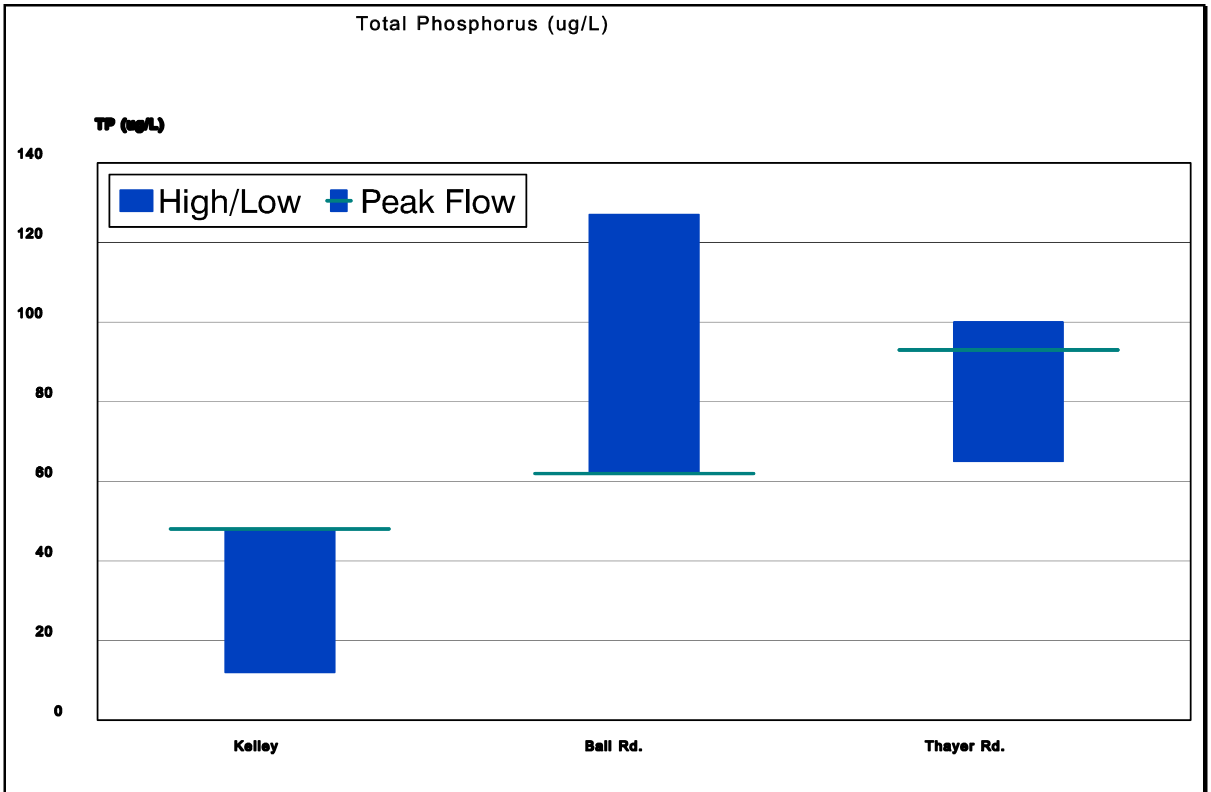
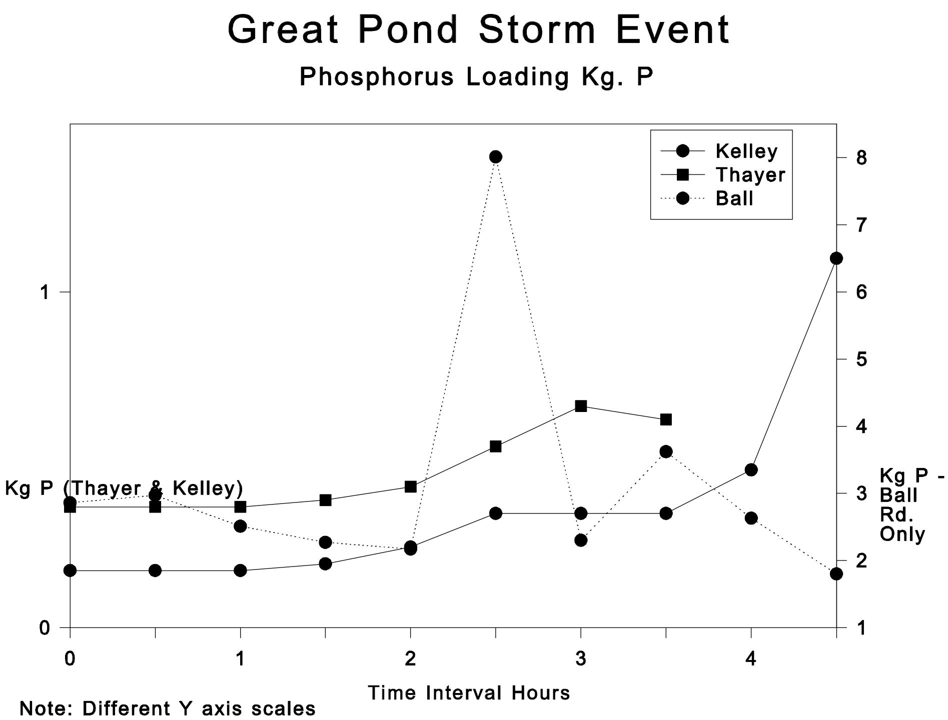


Figure VIII-8 Total Phosphorus Concentration and Peak Flow During the Great Pond Storm Event

The rain event sampled in this study occurred on October 6, 1995, with the onset of the remnant of a tropical storm. The area received approximately 1.9 inches of rainfall during an estimated 10 hour event. The rainfall intensity was considered moderate to intermittent. The October storm resulted in a total phosphorus load of 15.8 kg to Great Pond, which is almost nine percent of the annual phosphorus budget. The hydrologic component of the storm event is presented in Chapter VII. The storm event peak flow discharge for the three major tributaries are presented in Figure VIII-7. As expected, Kelley Tributary represents a majority of the storm flow. However, as Figure VIII-8 depicts, the greatest phosphorus concentrations were measured in the Ball Road Tributary. While the lowest phosphorus concentration was measured in Kelley Brook.

The storm event phosphorus loading data, was calculated by multiplying stream discharge by phosphorus concentration at the time of sampling. Figure VIII-9 lists phosphorus loadings for each station at each interval sampled. Since subwatersheds are different in respect to geology, hydrology and land-use, each subwatershed responce rate for both maximum pollution load and peak flow will vary from tributary to tributary. Small urban subwatersheds react quickly and usually contribute large volumes of water and nutrients to the lake. Large forested subwatersheds produce slower peak flows and lower nutrient concentrations. Ball Road Tributary had a significant flush of phosphorus at 2.5 hours into the storm. Ball Road Tributary also measured the highest peak phosphorus loading (8.01 kgP) and the highest total phosphorus storm load (10.35 kgP).

Kelley Brook showed the lowest phosphorus storm load (1.91 kgP) and the largest elapsed time of peak phosphorus loading. The Kelley Brook maximum peak loading of 1.1 kgP was not measured until 4.5 hours after the event began. The Ball Road Tributary contributed 2.07 kgP per hour of storm duration while Thayer Brook contributed 0.89 kgP per Figure VIII-10 Great Pond Storm Event Phosphorus Loadinghour and Kelley Brook 0.38 kgP per hour.


Great Pond Storm Event
Phosphorus Loading Kg. P
Kelley
Thayer
Ball
Kg P (Thayer & Kelley)
Kg P - Ball Rd. Only
Time Interval Hours
Note: Different Y axis scales
0
1
2
3
4
5
6
7
8